

# NASA SBIR Subtopic S2.04 “Advanced Optical Components”

H. Philip Stahl, Ph.D.  
Sub-Topic Manager

# What I want to see in a Proposal

Define a customer or mission or application and demonstrate that you understand how your technology meets their science needs.

Propose a solution based on clear criteria and metrics

Articulate a feasible plan to:

- fully develop your technology,
- scale it to a full size mission, and
- infuse it into a NASA program

Deliver Demonstration Hardware not just a Paper Study, including :

- documentation (material behavior, process control, optical performance)
- mounting/deploying hardware

# Customer / Application

While the ASTRO2010 Decadal Report has not yet been released,

Astrophysicists want bigger and better space telescopes:

- 4 to 8 m class monolithic primary mirrors for UV/optical or infrared
- 8 to 30 m class segmented primary mirrors for UV/optical or infrared
- 8 to 16 m class segmented x-ray telescope mirrors
- 8 to 10 m UV-transparent refractive Fresnel or diffractive lens

UV/optical telescopes (such as ATLAST-9 or ATLAST-16) require:

- 1 to 3 meter class mirrors with  $< 5$  nm rms surface figures
- broadband (from 100 nm to 2500 nm) high-reflectivity coatings with extremely uniform amplitude and polarization
- anti-reflection coatings on PMMA Fresnel lenses.

IR telescopes (such as SAFIR or CALISTO) require:

- 2 to 3 to 8 meter class mirrors with cryo-deformations  $< 100$  nm rms.

X-ray telescopes (such as IXO or GenX) require:

- 1 to 2 meter long grazing incidence segments,
- angular resolution  $< 5$  arc-sec to 0.1 arc-sec,
- and surface micro-roughness  $< 0.5$  nm rms.

# The Problems

## Cost

Large Space Telescopes are Expensive.

And Budgets are Constrained.

## Performance

Some desired capabilities do not yet exist:

- Large Deployable Mirror Segments

- Ultra-Stable Large-Aperture Segmented Mirrors

- Optical Coatings

# Heavy Lift

Currently, the President and Administrator both assert that we will start building a new Heavy Lift Launch Vehicle by 2015.

But, I don't know what will be the capacities of this new vehicle

It is probably safe to assume that the fairing diameter will be between 5 meters (EELV class) and 10 meters (Ares V class)

There is no way to predict L2 mass capabilities.

Direct Insert versus LEO Refueling

Current LEO mass capability is approx 20,000 kg

Current L2 mass capability is approx 6,500 kg.

# The Metric

For current launch vehicles, mass (areal density) is an important limitation, but this constraint could be significantly relieved via a heavy lift launch vehicle.

Therefore, areal cost (cost per square meter of collecting aperture) rather than areal density is the single most important system characteristic of future advanced optical system.

Currently, both x-ray and normal incidence space mirrors cost \$3M to \$4M per square meter of optical surface area.

This research effort seeks a cost reduction for precision optical components by 20X to 100X to less than \$100K/m<sup>2</sup>.

# The Challenge

The primary purpose of this subtopic is to develop and demonstrate technologies to manufacture ultra-low-cost precision optical systems for very large x-ray, UV/optical or infrared telescopes.

Potential solutions include but are not limited to:

- new mirror materials such as Silicon carbide or nanolaminates or carbon-fiber reinforced polymer;
- new methods to fabricate mirror substrates using conventional materials;
- new fabrication processes such as direct precision machining, rapid optical fabrication, slumping or replication technologies to manufacture 1 to 2 meter (or larger) precision quality mirror or lens segments (either normal incidence for UV/optical/infrared or grazing incidence for x-ray);

Additional key enabling technology for UV/optical telescopes are:

- broadband (from 100 nm to 2500 nm) high-reflectivity mirror coating with extremely uniform amplitude and polarization properties which can be deposited on 1 to 3 meter class mirror;
- anti-reflection coatings which can be deposited onto 2.5 meter diameter PMMA Fresnel lenses

# Deliverables

Phase I deliverable will be:

- at least a 0.25 meter near UV, visible or x-ray precision mirror or lens or replicating mandrel,
- optical performance assessment and
- all data on the processing and properties of its substrate materials.

This effort will allow technology to advance to TRL 3-4.

Phase II deliverable will be:

- at least a 0.50 meter near UV, visible or x-ray space-qualifiable precision mirror or lens system with supporting documentation,
- optical performance assessment,
- all data on materials and processing,
- plan for how to scale-up to 1 to 2 meter, and
- thermal and mechanical stability analysis.

Effort will advance technology to TRL 4-5.

# S2:04 Advanced Optical Component Systems.

Future heavy lift launch systems will enable extremely large and/or extremely massive space telescopes. Potential systems include 12 to 30 meter class segmented primary mirrors for UV/optical or infrared wavelengths and 8 to 16 meter class segmented x-ray telescope mirrors.

These potential future space telescopes have very specific mirror technology needs. UV/optical telescopes (such as ATLAST-9 or ATLAST-16) require 1 to 3 meter class mirrors with  $< 5$  nm rms surface figures. IR telescopes (such as SAFIR/CALISTO) require 2 to 3 to 8 meter class mirrors with cryo-deformations  $< 100$  nm rms. X-ray telescopes (such as IXO and GenX) require 1 to 2 meter long grazing incidence segments with angular resolution  $< 5$  arc-sec down to 0.1 arc-sec and surface micro-roughness  $< 0.5$  nm rms. Additionally, missions such as EUSO and OWL need 2 to 9 meter diameter UV-transparent refractive, double-sided Fresnel or diffractive lens.

In view of the very large total mirror or lens collecting aperture required, affordability or areal cost (cost per square meter of collecting aperture) rather than areal density is probably the single most important system characteristic of an advanced optical system. For example, both x-ray and normal incidence space mirrors currently cost \$3 million to \$4 million per square meter of optical surface area. This research effort seeks a cost reduction for precision optical components by 20 to 100 times, to less than \$100K/m<sup>2</sup>.

The primary purpose of this subtopic is to develop and demonstrate technologies to manufacture ultra-low-cost precision optical systems for very large x-ray, UV/optical or infrared telescopes. Potential solutions include but are not limited to new mirror materials such as Silicon carbide or nanolaminates or carbon-fiber reinforced polymer; or new fabrication processes such as direct precision machining, rapid optical fabrication, slumping or replication technologies to manufacture 1 to 2 meter (or larger) precision quality mirror or lens segments (either normal incidence for UV/optical/infrared or grazing incidence for x-ray).

Another key enabling technology is optical coatings. UV/optical telescopes require broadband (from 100 nm to 2500 nm) high-reflectivity mirror coating with extremely uniform amplitude and polarization properties which can be deposited on 1 to 3 meter class mirror. EUSO requires anti-reflection coatings which can be deposited onto 2.5 meter diameter PMMA Fresnel lenses. In both cases, ability to demonstrate optical performance on 2.5 meter class optical surfaces are important.

Successful proposals will demonstrate prototype manufacturing of a precision mirror or lens system or precision replicating mandrel in the 0.25 to 0.5 meter class with a specific scale up roadmap to 1 to 2+ meter class space qualifiable flight optics systems. Material behavior, process control, optical performance, and mounting/deploying issues should be resolved and demonstrated. The potential for scale-up will need to be addressed from a processing and infrastructure point of view.

An ideal Phase 1 deliverable would be a near UV, visible or x-ray precision mirror, lens or replicating mandrel of at least 0.25 meters. The Phase 2 project would further advance the technology to produce a space-qualifiable precision mirror, lens or mandrel greater than 0.5 meters, with a TRL in the 4 to 5 range. Both deliverables would be accompanied by all necessary documentation, including the optical performance assessment and all data on processing and properties of its substrate materials. The Phase 2 would also include a mechanical and thermal stability analysis.

Proposals should show an understanding of one or more relevant science needs, and present a feasible plan to fully develop a technology and infuse it into a NASA program.

## S2.04 & S2.05 Award Statistics Total

	Phase 1	Phase 2
2005	21% (8/38)	71% (5/7)
2006	28% (8/29)	63% (5/8)
2007	36% (4/11)	50% (2/4)
2008	59% (10/17)	50% (4/8)
2009	40% (8/16)	
Total	34% (38/111)	59% (16/27)

## S2.04 Award Statistics

	Phase 1	Phase 2
2005	22% (2/9)	100% (1/1)
2006	29% (6/21)	50% (3/6)
2007	33% (1/3)	100% (1/1)
2008	75% (3/4)	50% (1/2)
2009	66% (2/3)	
Total	35% (14/40)	60% (6/10)

## 2008 SBIR S2.04

Phase I

4 Submitted

3 Funded

**S2.04-9926 (MSFC) Low Cost Very Large Diamond Turned Metal Mirror,**  
Dallas Optical Systems, Inc.

**S2.04-9652 (MSFC) Silicon Carbide Lightweight Optics With Hybrid Skins**  
**for Large Cryo Telescopes,** Optical Physics Company

**S2.04-9748 (MSFC) A Low Cost Light Weight Polymer Derived Ceramic**  
**Telescope Mirror,** United Materials and Systems

Phase II

2 Submitted

1 Funded

**S2.04-9926 (MSFC) Low Cost Very Large Diamond Turned Metal Mirror,**  
Dallas Optical Systems, Inc.

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**S2.04-9926 Ph II Low Cost Very Large Diamond Turned Metal Mirror**

**PI: John M. Casstevens**

**Dallas Optical Systems, Inc. Rockwall, Texas**

**Identification and Significance of Innovation**

- Low Cost Mirror *SUBSTRATE* by Electroforming of NiP.
- Diamond Turning of NiP Electroformed Substrate.
- Very Low Cost Very Flexible Manufacturing Process for Large Mirrors.
- Low Areal Density, Very stiff metal mirror.

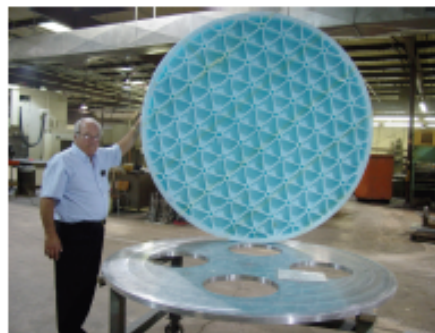
**Expected TRL Range at the end of Contract (1-9): 5-6**

— Continue to demonstrate a process for producing light weight, stiff mirror substrates by electroplating a NiP alloy over a low cost plastic foam mandrel which is removed with solvent after plating.

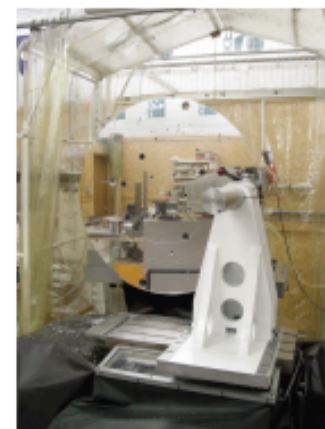
— Demonstration of diamond turning as a method of producing a high quality optical surface on the electroformed nickel phosphorus substrate by producing small (6-12 in.) and 600 mm (24 inch) dia. flat and spherical mirrors and deliver one 0.6 M finished mirror to NASA.

— Optical inspection of the finished mirrors to determine mechanical stability and stiffness and the extent of mirror internal structure print through on the finished optical surface as a function of faceplate thickness.

— Optical and dimensional inspection and characterization of the finished mirror for overall optical figure accuracy and surface smoothness achieved by diamond turning.



Machined 1.8 Meter Plastic Foam Mirror Substrate



Large cap. diamond turning machine

NASA's mission in space research includes some far-reaching research tools including Constellation-X, Generation-X, Terrestrial Planet Finder, Orbiting Wide Angle Light Collector, Cosmic Microwave Background Polarization (CMB-Pol), the Single Aperture Far-IR (SAFIR), the Sub-millimeter Probe of the Evolution of Cosmic Structure (SPECs) and Extreme Universe Space Observatory (EUSO).

*This innovative mirror manufacturing technology is applicable to all these projects as well as any military, scientific or commercial application requiring low cost light weight mirror optical components.*

**DOS** DALLAS OPTICAL SYSTEMS, INC.

John M. Casstevens, President  
1790 Connie Lane, Rockwall, Texas 75032  
972-564-1156

**NON-PROPRIETARY DATA**

## 2009 SBIR S2.04

Phase I

3 Submitted

2 Funded

**S2.04-8107 (MSFC) Very High Load Capacity Air Bearing Spindle for Large Diamond Turning Machines, Dallas Optical Systems, Inc.**

**S2.04-9341 (MSFC) Minimally Machined HoneySiC Mirrors for Low Areal Cost and Density, Trex Enterprises Corporation**

Phase II

TBD 2010

**S2.04-8107 Very High Load Capacity Air Bearing Spindle for Large Diamond Turning Machines**

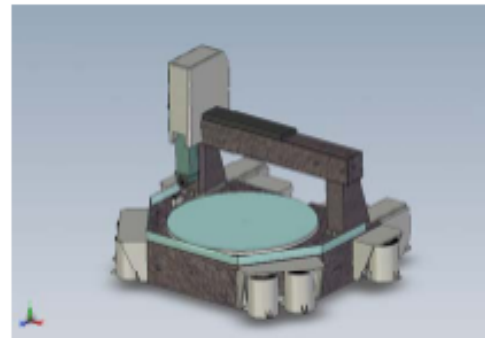
PI: John M. Casstevens

Dallas Optical Systems, Inc. Rockwall, Texas

Identification and Significance of Innovation

- Porous Graphite Air Bearing is the Key to Enabling a Practical Very Large Optics Diamond Turning Machine.
- Enables Diamond Turning of Very Large Optics.
- High Reliability Damage Resistant 20,000 lb. Capacity.
- Air Bearing Runs at High Speed Rotation without the Excessive Heat Generation of Oil Hydrostatic Spindles.

Expected TRL Range at the end of Contract (1-9): 4-5



Concept for 3 Meter Capacity Diamond Turning Machine



Dia. Turned IXO Mandrel

- Develop a manufacturing process for producing a reliable, high speed, very high load capacity air bearing spindle to enable diamond turning of very large optical components and demonstrate by building a 1/4 size prototype spindle.
- Test samples and select best porous graphite based on strength, stiffness, hardness, air flow properties and machineability.
- Use optical lapping and diamond turning to produce the high accuracy components and the precise assembly techniques required for air bearings.
- Optimize air flow modification techniques for porous graphite to obtain extreme dynamic stability throughout the spindle operating range of load and rotational speed.

NASA's mission in space research includes some very large optic research tools including International X-Ray Observatory (IXO), Constellation-X, Generation-X, Terrestrial Planet Finder, Orbiting Wide Angle Light Collector, Cosmic Microwave Background Polarization (CMB-Pol), the Single Aperture Far-IR (SAFIR), the Sub-millimeter Probe of the Evolution of Cosmic Structure (SPECs) and Extreme Universe Space Observatory (EUSO).

*This innovative spindle technology is potentially revolutionary enabling technology for all these NASA projects and any military or commercial ultra-precision large scale manufacturing or scientific experiment that needs extremely smooth and accurate rotary motion.*

**DOS** DALLAS OPTICAL SYSTEMS, INC.

John M. Casstevens, President  
1790 Connie Lane, Rockwall, Texas 75032  
972-564-1156

**NON-PROPRIETARY DATA**

## Minimally Machined HoneySiC Mirrors for Low Areal Cost and Density

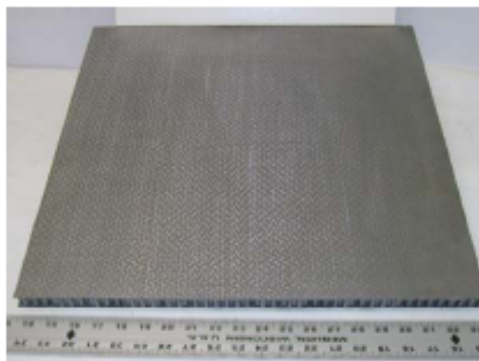
Trex Enterprises Corporation – San Diego, CA

PI: Dr. William A. Goodman

Proposal No: S2.04-9341

### Identification and Significance of Innovation

- Molded, Near net-shape T-300 carbon fiber prepreg is converted to silicon carbide. Web thickness <1-mm, core geometries (pocket depth, pocket size) easily tailored. **Minimizes machining and lightweighting.**
- Estimate HoneySiC Net Production cost ~\$38K/m<sup>2</sup>. ~40 to 100 times lower cost than current mirror technologies (\$3-4M/m<sup>2</sup>)
- <50% of beryllium density; HoneySiC panel density ~ 900 kg/m<sup>3</sup>
- CVC SiC™ facesheets replicated with figure from CVC SiC master mandrels – minimizes polishing.
- Estimate that large mirrors could be produced in a matter of weeks.
- Enter: TRL 2; Exit: Phase I at TRL 3, Phase II at TRL 5-6



Carbon-carbon honeycomb is converted to silicon carbide Honeycomb and clad with Replicated CVC SiC™ Facesheet

### Technical Objectives

Demonstrate processes for rapid and inexpensive production of large, high quality, lightweight silicon carbide mirrors. Specific objectives are:

- 1) Demonstrate the elimination or minimization of machining and lightweighting steps for open-and closed- back silicon carbide mirror panels.
- 2) Demonstrate proprietary release layer for polished silicon carbide mandrels which would allow direct replications of CVC SiC™ mirror facesheets

### Work Plan

- 1) HoneySiC Fabrication – Char carbon-carbon honeycomb (CCH) material. Coupons will be in configurations of bare honeycomb, honeycomb with a front facesheet, honeycomb with both front and back facesheets. Coupons will be round and from 5-10 cm in diameter. The coupons will be silicon infiltrated by Trex using a proprietary process. The pre- and post-infiltration coupon dimensions will be compared. Density of the resultant carbon fiber reinforced silicon carbide ceramic matrix composite will be measured to compare with expectations.
- 2) Mirror Replication Tasks – Trex shall use proprietary clad polished silicon carbide master mandrels (previously clad by Dr. Wil Zhang NASA GSFC) to perform replication deposition studies. We will produce thin CVC SiC™ facesheets for evaluation of figure and finish.

### NASA Applications

- Proposed innovations are directly relevant to the Technology Taxonomy for the Advanced Optical Component Systems subtopic – a) Sensors and Sources: High-Energy (ATLAST-16, ultraviolet), Large Antennas and Telescopes (ATLAST-16, ICESAT, LISA, SAFIR, CALISTO, JDEM, and ST-2020), and Optical (aspheres, off-axis aspheres, large segments); b) Materials: Ceramics, Composites, Optical and Photonic; and c) Structures: Kinematic-Deployable

### Non-NASA Applications

- DoD Imaging, Surveillance and Reconnaissance
- Giant Ground Based Telescopes

### Firm Contacts

Dr. Bill Goodman, PI, 858.437.3899  
bgoodman@trexenterprises.com

## S2.05 Award Statistics

	Phase 1	Phase 2
2005	21% (6/29)	67% (4/6)
2006	25% (2/8)	100% (2/2)
2007	38% (3/8)	33% (1/3)
2008	54% (7/13)	50% (3/6)
2009	46% (6/13)	
Total	34% (24/71)	59% (10/17)

## 2008 SBIR S2.05

### Phase I

13 Submitted

7 Funded

S2.05-8681 (JPL) **High Reflectivity, Broad-Band Silver Coating**, Surface Optics Corp

S2.05-8983 (GSFC) **Low-Stress Iridium Coatings for Thin-Shell X-Ray Telescopes**,  
Reflective X-ray Optics, LLC

S2.05-9001 (MSFC) **Application of Zeeko's Novel Random Tool Path for Improvement  
of Surface PSD**, Zeeko Technologies, LLC

S2.05-9323 (JPL) **Submicron Composite Mirror Replication**, DR Technologies, Inc.

S2.05-9500 (GSFC) **Super Polishing of 3D Aluminum 6061-T6 Mirrors**,  
Microengineered Metals, Inc.

S2.05-9876 (GSFC) **High-Speed Scanning Interferometer Using CMOS Image Sensor  
and FPGA Based on Multi-Frequency Phase-Tracking Detection**, Nanowave, Inc.

S2.05-9938 (GSFC) **RAP Figuring Slumped Mirrors to Remove Mid-Spatial Frequency  
Errors**, RAPT Industries, Inc.

### Phase II

6 Submitted

3 Funded

S2.05-8681 (JPL) **High Reflectivity, Broad-Band Silver Coating**, Surface Optics Corp

S2.05-8983 (GSFC) **Low-Stress Iridium Coatings for Thin-Shell X-Ray Telescopes**,  
Reflective X-ray Optics, LLC

S2.05-9938 (GSFC) **RAP Figuring Slumped Mirrors to Remove Mid-Spatial Frequency  
Errors**, RAPT Industries, Inc.

**NASA SBIR/STTR Technologies**  
**High Reflectivity, Broad-Band Silver Coating**



**PI: David Sheikh / Surface Optics Corporation (SOC)– San Diego, CA**  
**Phase II Proposal No.: 08-2 S2.05-8681**

**Identification and Significance of Innovation**

Silver coatings for optics greater than 2-meters in diameter are sought by NASA for future space telescope systems. In Phase I (SOC) investigated several new coating systems for protecting silver. The new designs are derivations of a patented coating design created at Lawrence Livermore National Laboratory (LLNL). The new designs improve the coating's reflectance performance, particularly in the UV region, while maintaining stability in harsh environments.

Expected TRL Range at the end of Contract (1-9): TRL6



**Technical Objectives and Work Plan**

Objective: Develop high UV and visible reflectance, durable silver coating, which is relatively easy to manufacture.

**Work Plan**

- Manufacture single layer coatings on Ag and test for durability upon exposure to H<sup>+</sup> and O<sup>+</sup> ions from an End-Hall ion source.
- Develop  $n, k$  data for selected materials out to a 1.1-meter radius.
- Optimize the coating uniformity over a 1.1-meter coating area.
- Fabricate and test alternative protected coating designs.
- Develop and implement an improved crystal monitor system using multiple sensors.
- Upgrade 3.3-m vacuum chamber by installing a plasma monitor system to detect contamination in the ion plume.

**NASA and Non-NASA Applications**

SNAP  
TPF  
Thirty meter telescope (TMT)  
Hobby-Eberly Telescope (HET)  
GTC is a 10 M; (36) 1.9M segments.

**Firm Contacts**

David Sheikh, PI, Surface Optics Corporation  
TEL: (858) 675-7404; [dsheikh@surfaceoptics.com](mailto:dsheikh@surfaceoptics.com)  
Jon Dummer, CEO/FSO; [jdummer@surfaceoptics.com](mailto:jdummer@surfaceoptics.com)  
Jill Trolinger, Contracts Representative; [jilt@surfaceoptics.com](mailto:jilt@surfaceoptics.com)

**NON-PROPRIETARY DATA**

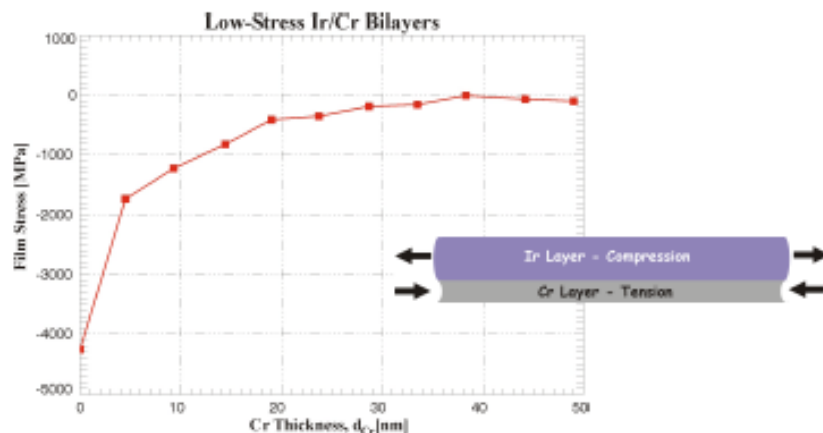
## Low-stress iridium coatings for thin-shell X-ray telescopes

PI: Dr. David L. Windt/Reflective X-ray Optics LLC, New York, NY

Proposal No: 08-2 S2.05-8983

Identification and Significance of Innovation

Develop and commercialize low-stress iridium coating technology for use in thin-shell X-ray telescopes such as the IXO FMA. The high stress in conventional Ir coatings causes large mirror substrate distortions that significantly degrade telescope resolution. New low-stress Ir coatings are thus urgently needed to meet the imaging requirements of IXO and other future X-ray astronomy missions.

Technical Objectives and Work Plan**Phase II Objective:**

Develop X-ray-reflective Ir coatings having low stress, low roughness and high density. We will build upon our successful Phase I work on the development of low-stress Ir/Cr bilayers and reactively-sputtered metal films.

**Phase II Work Plan:**

1. Complete investigations of Ir/Cr and Ir/Ti bilayers, and of Ir films and bilayers grown by reactive sputtering.
2. Coat GSFC-supplied thin mirror shells with low-stress Ir film technology, and conclusively demonstrate reduced substrate distortions.

NASA and Non-NASA Applications

The low-stress Ir coatings we propose to develop will be suitable for use in the IXO FMA telescope, as well as other future NASA X-ray telescopes comprising thin shell mirror elements.

Low-stress Ir X-ray coatings might also find application in non-NASA applications, such as diagnostic medical and homeland security (i.e., baggage and cargo screening) X-ray imaging.

Firm Contacts


Dr. David L Windt  
davidwindt@gmail.com  
212-678-4932

## NASA SBIR/STTR Technologies



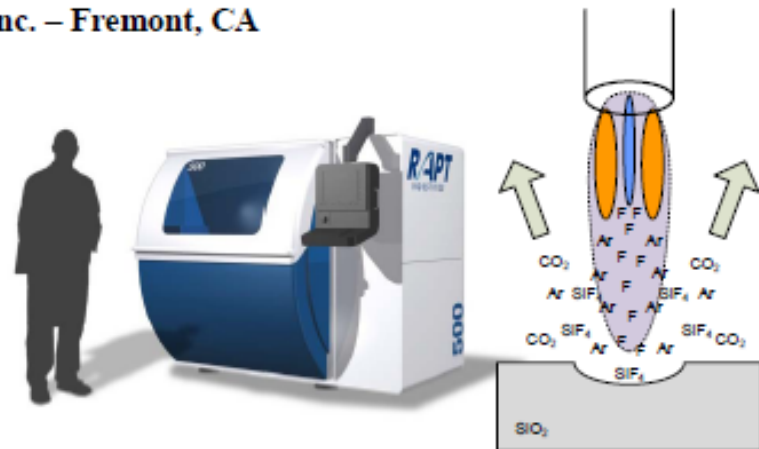
Proposal: S2.05-9938 RAP Figuring Slumped Mirrors to remove Mid-Spatial Frequency errors

PI: Pradeep Subrahmanyam  
RAPT Industries, Inc. – Fremont, CA

### Identification and Significance of Innovation

A slumping technique has been demonstrated to fabricate thin, lightweight shells for IXO mirrors. However, the optical surface is found to contain a significant amount of mid-spatial frequency errors. Reactive Atom Plasma (RAP) is a figuring technique that does not impart mid-spatial frequencies to the optical substrate geometries and can additionally remove specific spectra from the figure error. RAP has the ability to modulate tool footprint on the fly, allowing the removal of specific spatial frequencies from the error spectrum. RAP has already been demonstrated as a very credible approach for fabricating the lightweight wedges required for the assembly of such mirrors and is especially suitable for figuring extremely lightweight mirrors given the non-contact operation. In phase 1, we demonstrated the ability of the RAP process to impart minimal mid-spatial errors into the optical surface. A fully automated figuring platform with adjustable footprints is to be developed for phase 2. Up to ten slumped mirrors will be corrected to provide the desired error spectra (figure).

Expected TRL Range at the end of Contract (1-9): 5-6



### Technical Objectives and Work Plan

The main technical objective is to demonstrate the removal of the mid-spatial frequency errors on thin slumped glass substrates for use in the IXO program in a rapid, cost-effective manner meeting and exceeding all the outlined goals. The secondary objectives are to: 1) Develop and build a 5-axis RAP tool that can handle various prescriptions demanded by NASA X-ray mirror programs, 2) Develop the platform to have capability for modulating spot size on the fly to accommodate future requirements from NASA 3) Figure the slumped mirrors with a clear understanding of cost and lead time requirements.

Task 1: Torch redesign for laser/RAP - Capture heat and mass transfer studies into a newly redesigned torch, ready for integration with laser heating at a later date.

Task 2: Tool Design/Build – Design/Build a 5-axis RAP tool capable of 500 mm clear aperture and F/0.3 surfaces. Design in capability for laser-assisted RAP upgrades (at a later date).

Task 3: Productization – Work closely with NASA personnel to figure ten or more slumped mirrors. Using metrology data provided by NASA, construct optimal footprints/figuring approaches.

### NASA and Non-NASA Applications

Key NASA applications that could immediately use the technology are those involving high energy X-ray telescopes such as NuSTAR and IXO. The technology developed is also applicable to other NASA programs that seek to minimize payload without sacrificing sensor performance. Besides attenuating mid-spatics on such lightweight mirror segments, wedges can be etched on the back surface for assembly. The process can also be eventually used to direct-write gratings for local phase control on aspheric surfaces.

Making precision surfaces with a high aspect ratio is a common problem across optics, semiconductors, compound semiconductors, photo-voltaics etc. The high aspect ratio results from a need to reduce mass (as in the case of lightweight mirrors), improve device performance/packaging (as in semiconductors), decrease costs (as in photo-voltaics). The methods developed in Phase 1 can be applied to the rapid manufacturing of such surfaces in these other areas. RAPT Industries, Inc. has already commercialized the edge cleaning of semiconductor wafers through a licensing arrangement with Accretech, USA.

### Firm Contacts

Pradeep Subrahmanyam, Ph.D., President/CEO TEL: 510-933-1001

**NON-PROPRIETARY DATA**

# 2009 SBIR

Phase 1

13 Submitted

7 Funded

S2.05-8418 (**JPL**) **Springback-Compensated, Submillimeter Reflectors,**  
Vanguard Composites Group, Inc.

S2.05-8547 (GSFC) **Rapid Mandrel Fabrication of X-Ray Telescope,** OptiPro  
Systems LLC

S2.05-8780 (GSFC) **Coherent Laser Radar Metrology System for Large Scale  
Optical Systems,** Pyxisvision Incorporated

S2.05-9304 (GSFC) **In Situ Metrology for the Corrective Polishing of  
Replicating Mandrels,** Zeeko Technologies, LLC

S2.05-9386 (**MSFC**) **Removing Mid-Spatial Frequency Errors with VIBE,**  
Optimax Systems, Inc.

S2.05-9809 (GSFC) **Advanced Lightweight Metal Matrix Composite  
Segmented Optic Manufacture,** Hardric Laboratories, Inc.

Phase II

2010

Proposal No. S2.05-8418

Title: Springback-Compensated, Submillimeter Reflectors

## Identification and Significance of Innovation

Inconsistent radius of curvature of replicated, composite reflector panels limit application of composites to large, segmented telescope apertures. This project proposes to characterize and compensate for the behavior of affordable, graphite composite reflector sandwich panels suitable for large aperture, sub-millimeter space and earth science instruments. Advances in understanding and optimizing sandwich panel behavior may improve the radius repeatability and surface accuracy of PSR-style design approaches and enable science missions to obtain new levels of technical performance. If successful, the technology may also provide the means to reduce or eliminate the large number of actuators heretofore required to achieve a high precision surface. The focus of the innovation is to improve our ability to repeatedly obtain the desired radius of curvature by initially characterizing sandwich panel surface normal distortion due to cool down after cure on a spherical mold, identifying design and process parameters to reduce errors, and then, during Phase 2, compensate for this repeatable surface error (springback shape and magnitude) by intentionally machining a mold based on a surface definition that includes error correction.

TRL Range at the end of Contract (2):

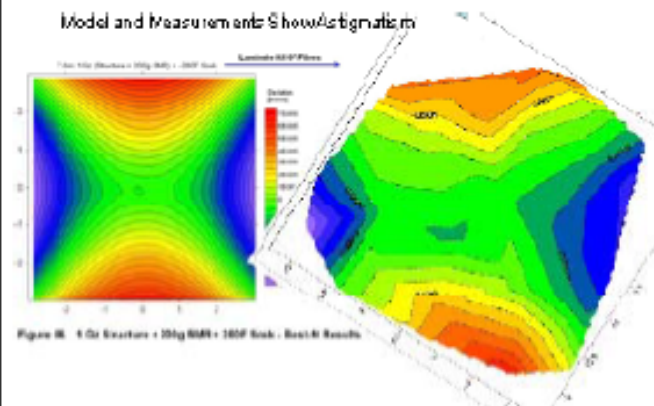


Figure 10: 1000 Elements x 1000 Nodes x 1000 Nodes x 1000 Nodes

## Technical Objectives & Work Plan

The overall objectives of this proposed effort are to: 1) characterize and statistically establish the radius of curvature repeatability of a 'typical' sandwich panel by fabricating and performing surface evaluation tests of several test specimens that have been simultaneously cured; 2) identify and demonstrate a sandwich design and process that contribute to the observed surface shape and magnitude; and 3) implement design features and processing controls that will lead to a replication accuracy of 1 micron RMS and provide acceptable radius of curvature repeatability. Hypothetical solutions to eliminate, significantly reduce, or mitigate the major error sources such as radius change include favorable ply stacking sequencing, tiling, or preferential stiffening. Phase 2 activities will include fabrication of a compensated mold and fabrication of large demonstration panels suitable for CCAT.

## NASA and Non-NASA Applications

Future NASA missions including the Cornell Caltech Atacama Telescope (CCAT) and Global Atmospheric Composition Mission (GACM), require 1 to 4 meter aperture, submillimeter-wavelength, primary reflector (mirror) segments.

## Firm Contacts

Eri Cohen (JPL)

Tom Sebring (Cornell)



**NON-PROPRIETARY DATA**

# NASA SBIR/STTR Technologies

## Removing mid-spatial frequency errors with VIBE

Optimax Systems, Inc. – Ontario, NY

PI: Jessica DeGroote Nelson

Proposal No.: S2.05 - 9386



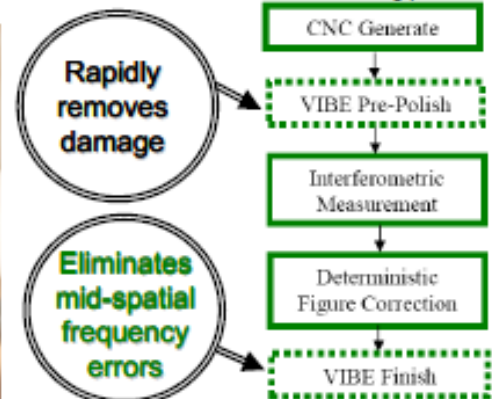
### Identification and Significance of Innovation

The Optimax VIBE process is a full-aperture, conformal polishing process incorporating high frequency and random motion to *eliminate mid-spatial frequency (MSF) errors* created by deterministic polishing in a VIBE finishing step while maintaining low spatial frequency form accuracy.

MSF errors are formed during deterministic sub-aperture polishing processes. MSF errors cause small angle scatter and flare in optical systems.

Estimated TRL at Beginning of Phase I: 2

Estimated TRL at End of Phase I: 3



### Technical Objectives and Work Plan

The technical objectives of this Phase I SBIR are to:

- Prove feasibility that VIBE will remove sub-aperture polishing marks from deterministically polished surfaces
- Determine optimum vibration frequency for efficiently removing the MSF errors with VIBE
- Determine optimum VIBE pad compliance to remove MSF errors
- Quantify MSF errors using standard interferometry

The work plan is divided into 3 major tasks:

1. Induce mid-spatial frequency errors on flat surfaces
2. Quantify errors with current metrology techniques
3. Implement VIBE finishing to reduce/remove MSF errors

### NASA and Non-NASA Applications

NASA:

X-Ray Telescopes: (IXO – slumping mandrels, produce surfaces less than 1.4nm rms between 2-20mm spatial frequency range.)

Exo-Planet Imaging Systems: (Minimize scatter on primary and secondary mirrors, specifically less than 1nm rms in 4-50 cycles/aperture range)

Non-NASA:

High Energy Laser Systems, EUV Optics (Lithography), Imaging Systems and X-Ray Synchrotron Optics

#### Firm Contacts

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**NON-PROPRIETARY DATA**

Any Questions?